Space Shuttle Cockpit Council

Cockpit Upgrade
Development Opportunities

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Vision for an Advanced Orbiter Cockpit

A human-machine interface designed to enhance safety and increase mission capability and effectiveness through the following implementation strategies:

- Maximize the crew vehicle and systems situational awareness
- Reduced flight workload through better displays and controls
- Increased levels of efficiencies in cockpit resource management (CRM)
- Training cost reductions and cost avoidance's
- Increased levels of flight crew autonomy in vehicle operations
- Computer assisted or automated control of complex procedures that require considerable training effort, extensive signature recognition skills, and are subject to human error, or distract the crew from critical mission duties
- Incorporate new techniques and technologies into the crewstation as required; however, new technology must earn its way on

Cockpit Upgrade Development Opportunities

Problem Definition Teams identified a Prioritized Set of Problems

1. Enhanced Caution and Warning
2. Abort Monitoring and Trajectory Assessment
3. RMS Workstation
4. Vehicle Systems Monitoring and Control Displays
5. Vehicle Instrumentation
6. Proximity and Docking Operations
7. MAL Procedures
8. Propulsion Systems: Performance and Control
9. Rendezvous Operations
10. Vehicle Data Accessibility

11. Flight Data File
12. Switches

Enhanced Caution and Warning

Current C&W system does not provide intuitive failure information in a succinct manner

- No centralized single point failure identification available for crew. The F7 panel, GPC messages, systems displays, and off flags/talkbacks must be used to piece together what the failure is. Crew is not immediately focused on the problem
- Failures can be masked by other failures or lost due to multiple messages
- Systems do not provide information but just data that have to be interpreted
- Too many lights and tones (both C&W and alert). Multiple system failures are tied to a single F7 light. Audible tones are too general. Results in information overload -- lights and tones are often ignored
- Large amount of training devoted to signature recognition (ie three phase motor stall)
- C&W does not have full data access (e.g. OI, GPC, SM, BFS, etc). This limits crew's ability to diagnose problem

Abort Monitoring and Trajectory Assessment

Vehicle abort monitoring and control is not intuitive nor integrated (Where can I go)

- Current vehicle abort monitoring/decision making requires analyzing information from multiple locations (PASS & BFS Traj, cue cards, flip books, flight instruments)
- PASS abort trajectory monitoring information is incomplete
- Trajectory displays must be timeshared with systems displays
- Displays do not provide sufficient resolution for accurate trajectory monitoring
- PASS and BFS information must be frequently compared, line by line
- Entry trajectories are not predictive -- manual energy calculations required
- Abort region awareness is limited to cue cards and look up tables
- ECAL monitoring and crew procedures are not integrated with vehicle display/control systems
- Difficult to assess options/tradeoffs during ECAL entry phase (Which is the best site)

Current and predicted trajectory is difficult to assess (Where am I , where am I going)

- Current vehicle trajectory monitoring requires viewing information from multiple locations (PASS & BFS Traj, cue cards, flip books, flight instruments)
- PASS trajectory monitoring information is incomplete
- Trajectory displays must be timeshared with systems displays
- Displays do not provide sufficient resolution for accurate trajectory monitoring
- PASS and BFS information must be frequently compared, line by line
- Entry trajectories are not predictive -- manual energy calculations required
- No knowledge of trajectory dispersions
- No knowledge of ETIP (range safety)

RMS Workstation

Accurate RMS position information and visual cues are not always available to the user
(Where is the Arm?)

- Lack of visibility for direct out the window views and camera views (obstructed views, CCTV washout, camera control problems, sun in FOV, no direct and/or camera views available)
- End effector location is considered accurate to only 2 inches and 1 degree due to boom flex, encoder accuracy, and thermal deformation. Tasks often require end effector accuracies well inside of these tolerances (ie Spartan berth)

- Lack of available data on the proximity of the arm and attached payload to structure
- Inability to accurately know where the arm is reduces operator SA

Lack of insight into the status of the RMS system
(How is the Arm?)

- Joint status not readily available (limits and singularities)
- Situational Awareness tools on PGSCs supply more information but there is at least a 2 second time delay for that information
- Detailed information on RMS failures available on the CRT is out of the view of the operator
- Non-RMS failure impacts are in Ref Data, not detailed, not accessible via computer, and not easily seen by the operator
- Signature recognition of failures can be difficult
- Inadequate information (position, attitude, joint angles) available to operator (A8 panel can only display three degrees of freedom at a time (position or attitude only) and only one joint angle value at a time)

Lack of adequate RMS operations control cues
(Where is the Arm going?)

- Lack of real-time path planning
- Steering cues available on PGSC's are delayed and based on encoder data, not more accurate sensor data
- Lack of good cues for SJ operations (best joint order, etc)
- Lack of insight into berthing envelopes
- No indications of how to avoid unwanted arm configurations (joint limits, singularities)
- No collision avoidance cues

Current non-integrated RMS toolsets are both cumbersome to operate and not always directly available (viewable) to the crew member

- Difficult for the operator to integrate several sources of information and not become overloaded (out the window, multiple camera views, A8 digitals, CRT displays, SVS, and situational awareness tools)
- Lack of sensor fusion for multiple sensors – inability to integrate sensor data from multiple sensors to determine which sensor is most accurate or how sensor data should be weighted
- PGSC/OSVS setup/cable routing/test time is significant. Real estate for mounting multiple displays limited

Vehicle Systems Monitoring and Control Displays

Systems Displays do not provide a clear and concise presentation of information to the crew

- Top level "big picture" on vehicle systems is not available. Crew has to search for and build systems situational awareness because of extraneous, buried and/or poorly displayed data in multiple locations
- Having to interpret data to get information induces errors and increases workload
- No trend or predictive information available
- Displays do not have full data access (e.g. OI, GPC, SM, BFS, etc). This limits crew's ability to diagnose problems and limits MEDS and C&W capabilities (ie COMM during ascent/entry)

Vehicle Instrumentation

Instrument crosscheck is not intuitive

- Meanings of displays change without a strong (or any) visual cue
- Accel tape, HSI, CDI, Velocity tape, H double dot tape, ADI, ADI rate needles
- Data is in the wrong place or format for an effective crosscheck
- Entry traj trailers but no predictors, theta limits, accel tape, wind data, Ascent planar steering (HSI), MEDS horizontal scan
- Some displayed data is not used (phase of flight dependent)
- H double dot in TAEM, delta H dot on ascent traj, some Entry traj digitals
- Too much raw data to interpret, not enough information
- Spec 50, Spec 55
- No clear warning when Del Az exceeded
- Poor use of colors by MEDS; bearing pointers blend together, digitals outside of crosscheck; no standard display styles/layouts
- Similar data scattered throughout the cockpit

Weak guidance/navigation to pilot interface

- Guidance doesn't always behave as a pilot would expect
- Sometimes too patient, sometimes too aggressive, no "smoothing"
- HUD guidance diamond not accurate enough; HUD FOV narrow
- Inconsistent use of predictive trajectory displays
- Entry TRAJ display difficult to monitor/fly from
- Source of info (guidance vs nav) not obvious on display
- Needles not always centered when guidance is good
- No limits indications on most displays
- No warning or guidance/autopilot limiting when approaching stall
- PASS Ascent TRAJ not useful in MM103
- HSI doesn't show what guidance is doing (OI-29 fix)

Proximity and Docking Operations

Cumbersome user interface causes prox ops to be too crew intensive

- Aft THC and RHC are not located or oriented consistent with control system response (e.g. a fly-to system). The aft controllers are not configured for either -X or -Z sense
- Dual configuration (-X or -Z) can create confusion as to which control orientation crew members are using and can result in input errors
- Displayed piloting cues are not located or oriented consistent with the control system response. (DAP panel also)
- Window view, relative motion plot may be blocked by other crew members in the cockpit (overcrowded cockpit, people and equipment)
- Systems failures require excessive attention/have to deduce impacts
- Parallax on CCTV plastic overlays.
- Direct and reflected sunlight wash out DAP Panel and monitors
- Current displays and tools require heads down flying
- Crew must access scattered, multiple displays. Systems monitoring required (Spec 33)

Prox OPS and Docking displays do not support rapid and efficient information processing

- Relative motion is only avail on PGSC (crit 2 vs 3) to aid in decision making
- Do not know relative position, closure, and attitude to the required accuracy
- Inadequate insight to orbiter attitude with respect to the target and the earth
- The ADI not tailored to prox-ops or orbit tasks
- No digital –Z sense information on UNIV PTG
- No LVLH display on UNIV PTG. No rotation option in LVLH (flyarounds)

- No insight is provided to the crew on plume/structural loads constraints
- Too many procedures and rules (lack of flexibility) to deal with the plume loads and contact conditions problem causes an overly complex timeline

MAL Procedures

MAL procedures are error prone and require excessive training

- Paper checklists are not interactive with C&W system and subsequent crew actions.
- Hard to interpret logic flow while in a dynamic environment
- Possibility to accidentally proceed down the wrong "leg" of the procedure
- Some MAL's are difficult to follow
- Some MAL's require multiple books for completion
- Example: FPC MAL which cover 10 procedures and 4 books before finishing (assuming no MCC)
- FDF is sometimes difficult to see during dynamic flight phases

Propulsion Systems: Performance and Control

Current and predicted engine performance and control difficult to assess (MPS/OMS/RCS)

- Current vehicle performance monitoring requires viewing information from multiple displays/ flight instruments
- Other systems failure impacts to performance not immediately available
- Systems displays must be timeshared with trajectory displays
- OMS/RCS burn targeting, execution, and monitoring displays and controls are cumbersome and non-intuitive
- Dump monitoring (timing and delta-V lost/gained) is limited and time-shared
- Total useable delta-V is not presented in a useful form
- OMS 1/2 burn situational awareness and strategy must be built from several sources

Rendezvous Operations

Rendezvous displays do not support rapid and efficient information processing

- Relative motion is only avail on PGSC (crit 2 vs 3) to aid in decision making
- Incorrect and/or misleading information is presented to the crew
- Predicted targeting solutions are not available to RPOP
- State vector and sensor performance have to be continually monitored
- There is no auto inhibit for sensor problems (star lock, F-P growth, FF3 fail...).
- MCC uplink is required to recover from Rendezvous NAV problems
- Inadequate insight to orbiter attitude with respect to the target and the earth
- The ADI not tailored to Rendezvous or orbit tasks
- Lack of MNVR completion time in MM 202 (A/E also)

Cumbersome user interface and procedures cause rendezvous to be too crew intensive

- Many multi-step, repetitive tasks that could easily be automated
- Crew must access scattered, multiple displays
- Over crowded cockpit (people and equipment)

- Window view, relative motion plot... may be blocked by other crew members in the cockpit
- Overly complex timeline
- In general, too many people monitoring stuff which would be better done by a computer (such as the sensor data on SPEC 33)
- Systems failures require excessive attention/have to deduce impacts

Vehicle Data Accessibility

Not able to monitor vehicle data and C&W on middeck or spacehab
- Takes time to get to flight deck to determine what the failure is
- Lost efficiency in addressing the failure
- Most activity is on middeck or spacehab
- Example is water dump where crew is going between flight deck and middeck trying to monitor system
- No C&W information other than audio available on middeck or spacehab

Flight Data File

Flight Data File operations concept/paradigm needs improvement
- Current C/L is difficult to see and use during flight
- Limited real estate for flying FDF
- Hard to interpret logic flow while in a dynamic environment
- Houskeeping difficult

Inconsistent nomenclature between switches, FDF, and display text
- Impedance for properly completing procedures
- Confusion
- Example: CCTV panel

Switches, Switches, and more Switches...

Too many switch throws required to accomplish a single function
- Inefficient use of existing cockpit switches
- Increases chances of errors by crew

Extraneous gauges and switches
- Takes cockpit real estate
- Additional training
- Examples: L2 emergency O2 switch, Dp/Dt switch, PL3 MDM switch, etc.

Proposed Upgrade Packages

The following Cockpit Upgrade Packages consolidate the above Problem Definitions into logical groups which can be worked separately

1. **Enhanced Caution and Warning**
    - MAL Procedures
    - Flight Data File
    - Vehicle Systems Monitoring and Control Displays

- Vehicle Data Accessibility

2. **Abort Monitoring and Trajectory Assessment**
   - Propulsion Systems: Performance and Control
3. **RMS Workstation**

4. **Rendezvous, Proximity and Docking Operations**

5. **Vehicle Instrumentation Upgrades**

Proposed Upgrade Package #1

Enhanced Caution and Warning	
MAL Procedures	Vehicle Systems Monitoring and Control Displays
Flight Data File	Vehicle Data Accessibility

Envisioned Solutions...
- Display that provides a single point of systems failure identification, both audio and visual
- Tailored to phase of flight and interactive with required procedural actions
  - Indicating significant consequences resulting from each failure
- Ties directly into systems synoptic displays
- **<u>Must replace the existing software and hardware C&W systems</u>**

Systems Displays:
- A display will show top level current status of all systems
- Hot keys will be used for display navigation down to the lower levels
  - Individual systems synoptic displays
  - Tailored to phase of flight and tied to previous failures
- **<u>Replaces current system summaries and other systems GPC pages</u>**

MAL Procedures/FDF:
- Smart checklist: Ties systems malfunctions (including C&W and systems displays) to
  - Procedures required
  - Actions taken
- Interactive system knows vehicle status and provides updated procedure based on configuration
- **<u>FDF replacements are required to be completely portable and has to be as easy to use as the current paper system</u>**

Envisioned platform requirements…
- ECW full implementations will require Mission Computer (AIPT Block 1) and possibly Enhanced MEDS (AIPT Block 2)
- Interim capability implementations will be used for proof of concept and small payback situations
  - Using existing MEDS/GPC avionics architecture
  - Possible PGSC on-orbit DTO’s

Proposed Upgrade Package #2

Abort Monitoring and Trajectory Assessment
Propulsion Systems: Performance and Control

Envisioned Solutions…
- Display formats automatically change during phase of flight to provide
  - Vertical and horizontal situational awareness
  - Deviations from nominal
- High resolution predictive displays fully integrated with the flight instruments

- A horizontal situation display will include 0, 1, 2, and 3 out engine predictive flight envelopes during ascent
  - Scale appropriately based on failures.
- Provide an on-orbit moving map with anytime deorbit capability
- Show entry flight envelopes with available landing sites, crossrange capability, and downrange capability.

Propulsion Systems:Performance and Control
- A display that combines burn delta V available (& options available based on delta V) with
  - Targeting,
  - Maneuvering
  - Burn performance

Envisioned platform requirements…
- Abort Monitoring and Trajectory Assessment full implementation will require
  - Mission Computer (AIPT Block 1) and possibly Enhanced MEDS (AIPT Block 2)
- Interim capability implementations can take advantage of existing MEDS/GPC avionics architecture

Proposed Upgrade Package #3

RMS Workstation

Envisioned Solutions…
- Provide graphical/pictorial tools to support improved situational awareness
- Software analyzes and integrates data from multiple sensors, providing:
  - Accurate, real-time (no time delay) RMS position, attitude, and force information
- Displays would assist the operator in avoiding joint limits, structure, and excessive arm loads
- Provides the operator with control cues for path planning
- Improved cameras, camera views, and targets would provide improved visual feedback
- Provide automated failure recognition aids
- Workstation displays and controls are within a good scan pattern for the operator
- Options for viewing the displays would include
  - Display monitors integrated into the A8 panel
  - Overlays on video images
  - HUD overlayed onto out the window views
  - Laptop computers
  - Head mounted display
- Input mode shaping and active damping

Envisioned platform requirements…
- RMS Workstation full implementation will require
  - D&C panel upgrade architecture
- Interim capability implementations can take advantage of existing MEDS/GPC avionics architecture and PGSC's

Proposed Upgrade Package #4

Rendezvous, Proximity and Docking Operations

Envisioned Solutions…
- Incorporates multi-sensor (and/or system) integration (information presentation vs. data presentation)
- Shuttle aft and forward station will be a workstation environment allowing multiple displays
- Displays allow for video repeating
- Several overlay options will also be present (e.g. centerline overlay and ranging ruler, etc….)
- The sensors will give the crew positional information (R, Rdot, etc.…) to the resolution required to support:

    - Rendezvous/Prox Ops phases and docking contact conditions
- Software will be able to view the main object compute the range, range rate and relative attitude
- Relative motion plots with current prediction as well as future burn predictions will be available
- Rendezvous should utilize automation to:
    - Eliminate repetitive crew tasks and multiple inputs
    - Support crew consensual tasks and commands
- Reduce the crew required to two

Envisioned platform requirements…
- Rendezvous, Proximity and Docking Operations full implementation will require:
    - D&C panel upgrade
    - Mission Computer (AIPT Block 1), possibly Enhanced MEDS (AIPT Block 2)
- Interim capability implementations can take advantage of existing MEDS/GPC avionics architecture and PGSC's

Proposed Upgrade Package #5

Vehicle Instrumentation Upgrades

Envisioned Solutions…
- Flight instruments with a crosscheck tailored and simplified to phase of flight
    - Clearly displaying all applicable flight envelope limitations
    - Designed to work with vertical and horizontal situation displays
- Displays will be based on current industry standards

Envisioned platform requirements…
- Vehicle Instrumentation Upgrades full implementation will utilize existing MEDS/GPC avionics architecture requiring MEDS/GPC software CR's
- Enhanced capabilities will be enabled through implementation of:
    - Mission Computer (AIPT Block 1), Enhanced MEDS (AIPT Block 2)